An Integrated modeling and Observational Study of Three-Dimensional Upper Ocean Boundary Layer Dynamics and Parameterizations

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LONG-TERM GOALS

This study contributes to our long-term efforts toward understanding:

- Mixed layer dynamics and lateral mixing in the upper ocean.
- Processes that communicate atmospheric forcing to the ocean interior.

OBJECTIVES

Existing high resolution regional models typically resolve the mean vertical structure of the upper ocean boundary layer. Physically-based parameterizations of vertical fluxes make it possible to account for subgrid mixing at length scales smaller than the layer depth, but no specialized parameterization is used to represent the dynamics of horizontal mixing below the O(1)*km* - O(10)*km* resolution scale. We aim to determine the physical limitations of subgrid parameterization on these scales. This project will address the following questions:

- What physics govern horizontal and vertical mixing in the presence of horizontal variability on the 1-10 km scale?
- What is the relative importance of horizontal and vertical mixing in determining the structure of the boundary layer?
- How well can existing parameterizations simulate vertical and horizontal mixing?
- What physics should be included to improve parameterizations?

APPROACH

An adaptive measurement program employed acoustically-tracked, neutrally buoyant Lagrangian floats and a towed, undulating profiler to investigate the relative importance of vertical and horizontal mixing in governing boundary layer structure in the presence of O(1 km) scale horizontal variability. Remotely sensed sea surface temperature and ocean color, combined with rapid, high-resolution towed surveys and model results guide float deployments to key locations within fronts. Synoptic, high-resolution surveys followed Lagrangian float drifts to characterize three-dimensional variability within

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the span of a model grid points. Acoustic tracking allowed towed surveys to follow floats and geolocated all observational assets for later analysis. Measurements characterized boundary layer turbulence and facilitate detailed separation of vertical and horizontal processes.

A turbulence-resolving Large Eddy Simulation (LES) will model the dynamics of vertical and horizontal mixing in a domain volume corresponding to a regional model's horizontal gridscale and set in the translating Lagrangian reference frame of the float/survey observations. The observations will provide realistic initial and time-dependent boundary conditions and, in particular, time-dependent lateral boundary conditions will be determined from rapid surveys.

Quantitative one-to-one statistical comparisons between LES results and the float and survey observations will be made. This product will have direct application to assessing regional model subgrid parameterizations.

WORK COMPLETED

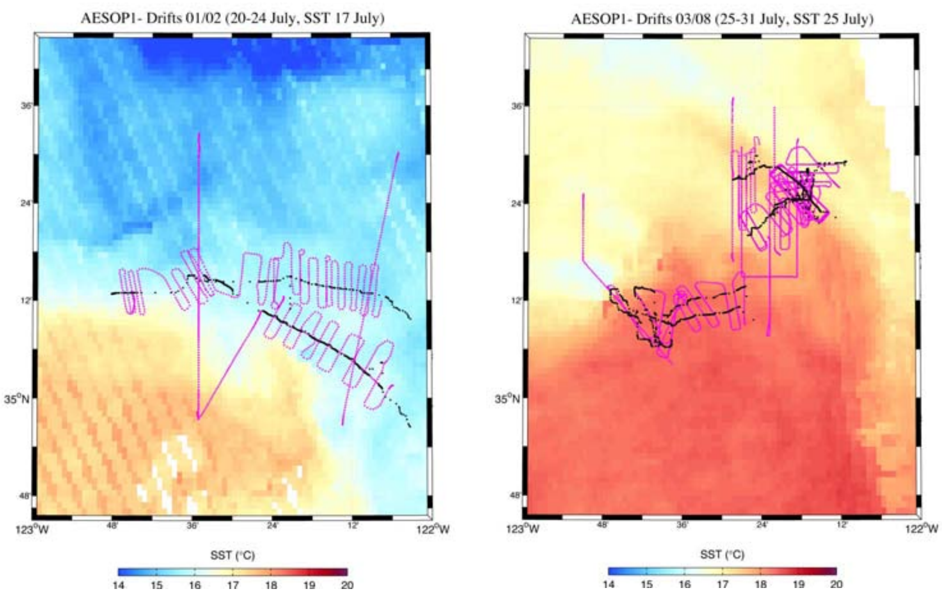

Figure 1. Float drift (black) and towed profiler (magenta) tracks plotted over remotely sensed sea surface temperature. The bathymetry rises from the abyss near the eastern margin of the chart.

The first of two cruises associated with this AESOP effort took place from R/V Roger Revelle, 16 July – 8 August 2006 off the California coast. Operations began with instrument testing and acoustic tracking refinement in the Channel Islands and Santa Barbara channel. Following this, two drifting surveys focused on a zonally oriented front located west of the continental rise off of San Luis Obispo (Fig. 1). A third drift followed the southward flow associated with a strong meridionally oriented front (Fig. 2). Sections occupied prior to float deployment exhibit T-S characteristics, small pycnostads and optical signatures that suggest active subduction of cold-side waters into the region below the warm-side mixed layer base (Fig. 2). Informed by float behavior inferred from model results analyzed before the cruise and by the high-resolution towed profiler section occupied immediately prior to float deployment, we selected a site intended to maximize the probability of observing subduction. Our first few deployments, during periods of weak wind, found little evidence for subduction driven by submesoscale processes alone. Our final two deployments, spanning a period of rising, sustained and then relaxing winds, clearly showed subduction and restratification as the front relaxed after the wind dropped.

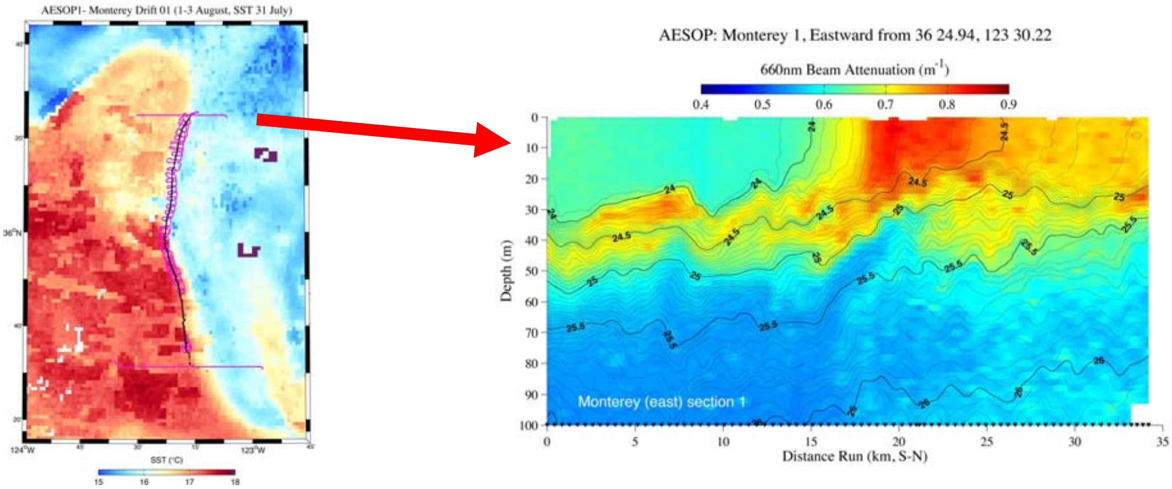

Figure 2. (left) Front-following drift with line colors as defined in Fig. 1. (right) Potential density (contours) and 660 nm beam attenuation (colors) from the section used to choose the float deployment site.

RESULTS

Our most dramatic results show rapid mixed layer restratification in the presence of strong lateral density gradients. Sampling began during a period of 20 – 30 kt winds with 30-m deep mixed layers in the region of strongest lateral density gradients associated with an upper ocean front. Winds weakened to 5 – 10 knots over a 12-hour period, during which observations captured a continuous sequence of sections around a drifting float. When mapped into the drifting reference frame, the extended survey path collapses into a dense pattern of sections, roughly 5 km by 5 km, characterizing the volume surrounding the float (Fig. 3). In this region, the mixed layer rapidly slumped as winds weakened, with lighter waters overriding waters from the front's dense side to produce a fully stratified boundary layer within a 20-hour inertial period (Fig. 4). Strong intrusions, visible in temperature, salinity and chlorophyll fluorescence, also contributed to stratification changes, especially in the region beneath the 24.5 kg/m3 isopycnal that initially defined the mixed layer base.

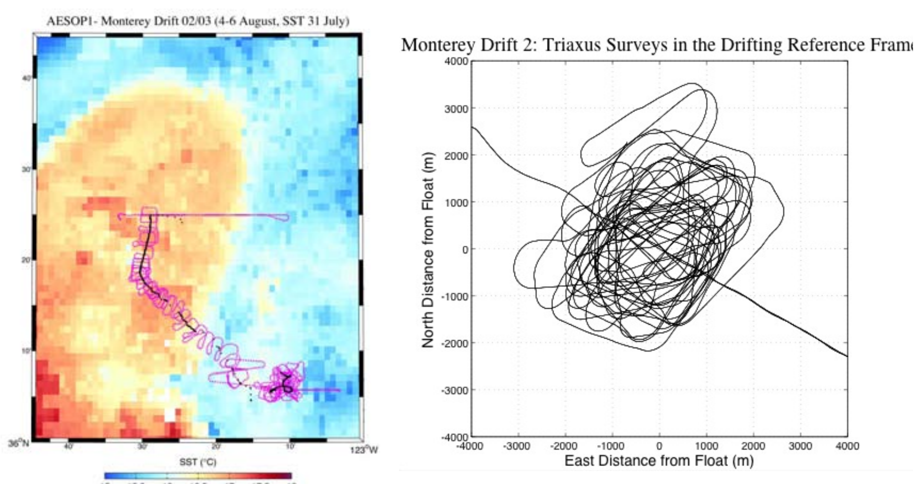

Figure 3. (left) Restratification drift, with line colors as defined in Fig. 1. (right) Towed profiling survey track mapped into the float-following reference frame.

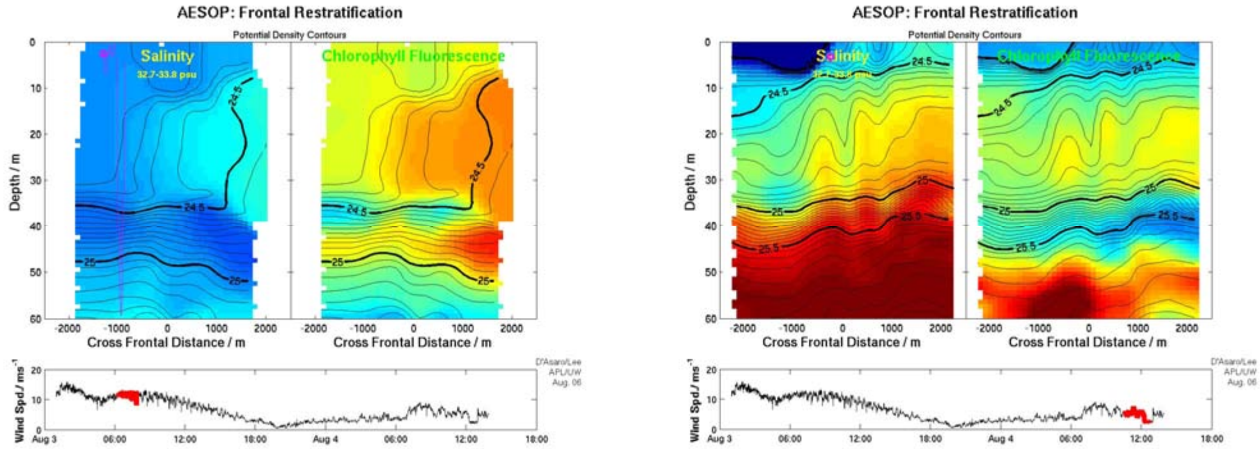

Figure 4. Potential density (contours) and salinity/chlorophyll fluorescence (colors) along a section projected though the center of the drift-following survey (depicted in the right panel of Fig. 3). The bottom axis displays wind speed throughout the entire drift, with the red line indicating the timeframe of the section displayed above. The left panel depicts conditions shortly after deployment, when wind speeds of 30 knots maintained a 30-m deep mixed later. The right panel displays conditions observed near the end of the deployment, when winds had dropped to 10 knots. With weakening winds, the mixed later slumps and lighter waters override denser masses to drive rapid restratification. Lateral intrusions of warm, saltier waters (also apparent in elevated fluorescence) are visible below the 24.5 kg/m3 isopycnal.

IMPACT/APPLICATION

Interactions with the ASAP program led to improvements in Monterey Bay 2006 model predictions.

TRANSITIONS

None.

RELATED PROJECTS

SeaSoar and Doppler Sonar Spatial Survey of Internal Tide Generation and Mixing, Shaun Johnston and Daniel Rudnick.

MB06 programs (e.g. ASAP, PLUSNet).

REFERENCES

None.

PUBLICATIONS

None.